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SIMULATION OF THE LAUNCHING PHASE OF THE MARK 8 PUMP-JET TEST VEHICLE.

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ABSTRACT

The behaviour of the Mark 8 torpedo pump jet test vehicle was studied in the acceleration phase from launching at 25 knots to steady running at 45 knots. The effect of locking the elevators during the initial acceleration was considered for three configurations of the torpedo.

22 pages
12 figures

INTRODUCTION

In an attempt to explain the behaviour of the Mark 8 Pump-jet test vehicle, it was decided that a more detailed simulation of the control system characteristics was required. This simulation was to include non-linearities, such as end-stops, and the effect of body accelerations on the pendulum.

A detailed experimental examination of the actual control system was made in which the characteristics of the system were determined. From these figures it was possible to simulate the behaviour of the control system more exactly.

Three configurations of the body were considered, two cg. positions, one with a tail ring added.

THE EQUATIONS OF MOTION OF THE TORPEDO

In a preliminary simulation it was assumed that the stability derivatives were calculated for a forward speed of 45 knots and the motion of accelerating from 25 knots was taken as a perturbation. As this was rather a large variation of speed the above method was compared with a simulation in which the stability derivatives were calculated as a function of the actual speed. The two methods differed sufficiently to justify the extra complication of varying the derivatives with speed which gives the more exact simulation.

The actual speed V is given by:-

$$V = (76 + u) \text{ ft/sec.}$$

The equations of motion then become:-

$$(X_{\dot{u}} - m)\,\dot{u} + \frac{X_u}{76} \cdot Vu - mw\dot{\theta} = 0$$

$$(Z_{\dot{w}} - m)\,\dot{w} + \frac{Z_w}{76}.\, Vw + \frac{(Z_{\dot{\theta}} + mu_1)}{76}.\, V\dot{\theta} + Z_{\ddot{\theta}}.\,\ddot{\theta} + \frac{Z_\delta}{(76)^2}.\, V^2\delta = 0$$

$$(M_{\ddot{\theta}} - I_y)\ddot{\theta} + \frac{M_{\dot{\theta}}}{76}.V\dot{\theta} + \frac{M_w}{76}.Vw + M_{\dot{w}}.\,\dot{w} + \frac{M_\delta}{(76)^2}.V^2\delta + B.\Delta = 0$$

$$\text{and } \dot{z} + V\theta - w = 0$$

The transformation equations are:-

$$U = 2u \qquad W = 10w \qquad \Theta = 114.6\theta \qquad \bar{V} = V$$

$$P = p \qquad Z = 2z \qquad \bar{\delta} = 1146\,\delta$$

$$\bar{\eta} = 114.6\eta \qquad \bar{\xi} = 573\,\xi$$

These give the machine equations

$$(X_{\dot{u}} - m)\,\frac{PU}{2} + \frac{X_u}{76}.\frac{\bar{V}U}{2} - \frac{mWP\Theta}{1146} = 0$$

$$(Z_{\dot{w}} - m)\frac{PW}{10} + \frac{Z_w}{76}\cdot\frac{\bar{V}W}{10} + (Z_{\dot{\theta}} + mu_1)\frac{\bar{V}P\theta}{76 \times 114.6} + Z_{\ddot{\theta}}\cdot\frac{P^2\theta}{114.6} + \frac{Z_\delta}{(76)^2}\cdot\frac{\bar{V}^2\bar{\delta}}{1146} = 0$$

$$(M_{\ddot{\theta}} - I_y)\frac{P^2\theta}{114.6} + \frac{M_{\dot{\theta}}}{76}\cdot\frac{\bar{V}P\theta}{114.6} + \frac{M_w}{76}\cdot\frac{\bar{V}W}{10} + M_{\dot{w}}\cdot\frac{PW}{10} + \frac{M_\delta}{(76)^2}\cdot\frac{\bar{V}^2\bar{\delta}}{1146} + B\Delta = 0$$

$$\frac{PZ}{2} + \frac{\bar{V}\theta}{114.6} - \frac{W}{10} = 0$$

Substitution of the relevant figures from Table 1 and rearrangement of the equations gives:-

$$10\,PU + 0.078\,\bar{V}U + 0.01708\,WP\Theta = 0$$

$$PW + 0.0241\,\bar{V}W - 0.0142\,\bar{V}P\Theta + 0.00278\,P^2\Theta + 0.0000808\,\bar{V}^2\bar{\delta} = 0$$

$$P^2\Theta + 0.0981\,\bar{V}P\Theta - 0.0589\,\bar{V}W + 0.1295\,PW + 0.000409\,\bar{V}^2\bar{\delta} - 56.8\,\Delta = 0$$

$$PZ + 0.01746\,\bar{V}\Theta - 0.20\,W = 0$$

$$\bar{V} - 76 - 0.50\,U = 0$$

The flow diagram for these equations is given in figs. 1 and 2.

THE CONTROL SYSTEM

This has been dealt with in more detail in ref. 1.

The motion of the pendulum is described by:-

$$-I_P\ddot{\eta} - F\dot{\xi} - Wl\eta + C + A + H = 0$$

where

I_P	=	moment of inertia of the pendulum
η	=	angle to the true vertical
F	=	frictional or damping moment coefficient
ξ	=	angle rel. to torpedo body $\therefore\ \eta = \theta + \xi$
C	=	the moment due to centrifugal force on the pendulum arising from the rate of turn of the body
H	=	moment from depth pressure diaphragm
$Wl\eta$	=	righting moment due to gravity
θ	=	pitch angle of body
A	=	moment arising from accelerations, linear and angular.

REF. 1 RITTER, H. and GROVE, A.C., A non-linear Simulation of the Depth Control System of the Mark 8[xx] Torpedo. ARL/G/N12.

With the appropriate numerical values this equation becomes:-

$$\frac{1}{36}\ddot{\eta} + \frac{0.32}{6}\dot{\xi} + \eta + \frac{42}{32.2}\dot{\theta}\xi + \frac{1}{32.2}\dot{\theta}w + \frac{1}{32.2}\dot{u} - \frac{1}{32.2}\dot{w}$$

$$- (0.242 + 4.83\xi)\frac{1}{32.2}\ddot{\theta} - \frac{0.27}{57.3}z = 0$$

Using the above transformation equations and rearranging we have:

$$P^2\bar{\eta} + 0.384P\bar{\xi} + 36\bar{\eta} + 12.8\ PU - 10.45\ Z_{LIM} + L$$

$$+ \bar{\bar{\xi}}\left\{0.0822\ P\Theta - 0.0223\ PW - 0.0094\ P^2\Theta\right\}$$

$$+ W\left(0.112\ P\Theta\right) - 0.2710\ P^2\Theta = 0$$

Also $$0.1\ \bar{\xi} + 0.5\ \Theta - 0.5\ \bar{\eta} = 0$$

$$\bar{\delta} = -2\bar{\xi}$$

Z_{LIM} is the depth term Z limited to +68 volts on the positive side. This corresponds to a depth limit of +34 ft, due to the springs in the link box.

The moment L represents a semi-elastic stop at $\bar{\xi} = \pm 35$ volts which is the range of pendulum swing relative to the torpedo body.

It is shown in ref. 1 that the non-linear terms $\bar{\bar{\xi}}\{0.0822\ P\Theta - 0.0223\ PW - 0.0094\ P^2\Theta\}$ and $0.112\ WP\Theta$ are negligible for the type of manoeuvre investigated here and hence they are omitted in the simulation. The control system includes a locking device which holds the elevators at a set angle for a pre-determined time from launching.

The flow diagram of the control system is given in fig. 3.

RESULTS

As little was known about the thrust of the pumpjet a comparison is shown (fig. 4) between the velocity trace from the computer and the first few seconds of two full-scale test runs. The initial accelerations are in reasonable agreement showing that the estimated thrust was comparable to that achieved in the test runs.

The early full-scale trials on the test vehicle were carried out on a short-nosed body ($l = 22.31$ ft, $x_G = 10.63''$ forward of mid-axis pt., 5.6" down aft trim and an estimated $G = 0.64$). As this body proved to be uncontrollable two remedies were tried on the torpedo

(a) The nose was lengthened to $l = 25.042$ ft giving $x_G = 1.44$ ft forward of the mid-axis pt., and zero down aft trim

and (b) various tail appendages were added to the normal length version. Three configurations, all of the long nosed body, are included in the present simulation.

(1) Long-nosed torpedo $l = 25.042$ ft. $x_G = 1.44$ ft. forward of the mid-axis pt. which gives zero down aft trim and $G = 0.64$

(2) Long-nosed torpedo $l = 25.042$ ft. $x_G = 0.75$ ft. forward of the mid-axis pt., which gives 0.67 ft. down aft trim and $G = 0.57$

(3) Long-nosed torpedo $l = 25.042$ ft. $x_G = 0.75$ ft. forward of the mid-axis pt. with a tail ring of $4\frac{1}{4}$" chord fitted behind the pump-jet. This gives $G = 0.91$ and 0.67 ft. down aft trim.

Figs. 5 and 6 show the depth traces for the body as (1) above. In fig. 5 the effect of a variation of the initial locked elevator angle (δ_1) is shown for a constant time of locking $T_1 = 5$ secs. $\delta_1 = 0$ gives a very small disturbance but $\delta_1 = \pm\frac{1}{2}^\circ$ causes the torpedo to diverge from its set depth by 25 ft. in one direction and 19 ft. in the other. Fig.6 shows the effect of a variation of T_1 for $\delta_1 = +\frac{1}{2}^\circ$. For $T_1 < 3$ secs. the disturbance is hardly affected but for $T_1 > 4$ secs. the peak depth is much larger.

Fig. 7 and 8 relate to the torpedo with reduced hydrodynamic stability (as(2) above). The effect of a variation of δ_1 is shown in fig. 7 and it is seen that for the least disturbance δ_1 should be about $+1\frac{3}{4}^\circ$. If $\delta_1 > +2\frac{1}{2}^\circ$ the torpedo will rise too quickly, overshoot the steady depth value, and may surface. For $T_1 < 6$ secs (fig. 8) the disturbance is very small, but for $T_1 = 7$ secs the depth trace shows the damped oscillation which for greater T_1 may cause the torpedo to rise too quickly and surface. The initial rise and final steady value are caused by the presence of 0.67 ft. down aft trim.

The addition of a tail ring (3 above) reduces the depth variation for given values of T_1 and δ_1 when compared with the previous cases. $\delta_1 = +2^\circ$ gives the least disturbance but the system can stand initial elevator angles as high as $\delta_1 = +3\frac{1}{2}^\circ$ and not show the oscillation of the previous configuration. Fig. 10 shows that provided $T_1 < 4$ secs. its actual value is immaterial.

Typical elevators traces for each configuration of the torpedo are given in Fig. 11.

Fig. 12 is a comparison of the depth traces of a full-scale run (No. 106 short body with tail ring, $x_G = 0.89$ ft. $\Delta = 0.467$ ft. $\delta_1 = +2\frac{1}{2}^\circ$, $T_1 = 4$ secs)and a computer run (long body with tail ring $x_G = 0.75$ ft., $\Delta = 0.467$ ft. $\delta_1 = +2.1^\circ$, $T_1 = 5\frac{1}{2}$ secs.). Note that the down aft trim has been reduced in this last simulation to that of the torpedo with which it is compared. In spite of the slight differences in the other parameters, there is good agreement between the two curves.

CONCLUSIONS

The behaviour of the long-nosed Mark 8 Pumpjet test vehicle has been investigated for two positions of the centre of gravity and with the addition of a tail ring.

Provided that the locked elevator angle is kept within fairly close limits $(< \pm \frac{1}{2}^{\circ}$ with $T_1 = 5$ secs) for the more suitable cases or that the time of locked elevator (T_1) is less than 4 secs. then all configurations are acceptable. With the extra tail ring and the consequent increase in stability the permissible range of initial elevator setting is more than doubled for $T_1 = 5$ sec.

If these parameters are above their respective limits then the torpedo will climb out of its dive so fast that it overshoots the steady state depth and may reach the water surface.

A. C. Grove (S.O.)

ACG/ES

TABLE 1

Details of the Mark 8^{XX} Torpedo (Long Nose)

Speed	=	76 ft/sec. accelerating from 42.2 ft/sec.
Length	=	300.5 ins = 25.042 ft.
Diameter	=	21 ins
Cross-Area	=	2.405 sq. ft.
C.G. position	=	167.5" from tail
C.B. "	=	167.5" " "
Buoyancy	=	3090 lb. (W-B) will be taken as zero
Weight	=	3170 lb.
Mass	=	98.45 slugs

Stability Derivatives

$$Z_w = \frac{\partial C_Z}{\partial \alpha} \times \tfrac{1}{2}\rho AV = -408.5$$

$$M_w = \frac{\partial C_M}{\partial \alpha} \times \tfrac{1}{2}\rho AVl = 2450$$

$$Z_q = \frac{\partial C_Z}{\partial q'} \times \tfrac{1}{2}\rho AVl = -4676.78$$

$$M_q = \frac{\partial C_M}{\partial q'} \times \tfrac{1}{2}\rho AVl^2 = -44946$$

$$Z_\delta = \frac{\partial C_Z}{\partial \delta} \times \tfrac{1}{2}\rho AV^2 = -11321$$

$$M_\delta = \frac{\partial C_M}{\partial \delta} \times \tfrac{1}{2}\rho AV^2 l = -147870$$

$$M_u = Z_u = 0$$

$$m_f = 121.84 \quad m_a = 5.95 \text{ slugs} \quad l_f = 11.907 \text{ ft.}$$

$$\therefore \quad X_{\dot{u}} = -2.0713 \qquad (I_y - M_{\ddot{\theta}}) = 6272$$

$$Z_{\dot{w}} = -124.26 \qquad (X_{\dot{u}} - m) = -100.52$$

$$Z_{\ddot{\theta}} = M_{\dot{w}} = -70.85 \quad (Z_{\dot{w}} - m) = -222.71$$

$$X_u = -59.4 \qquad mw_1 = 14.049$$

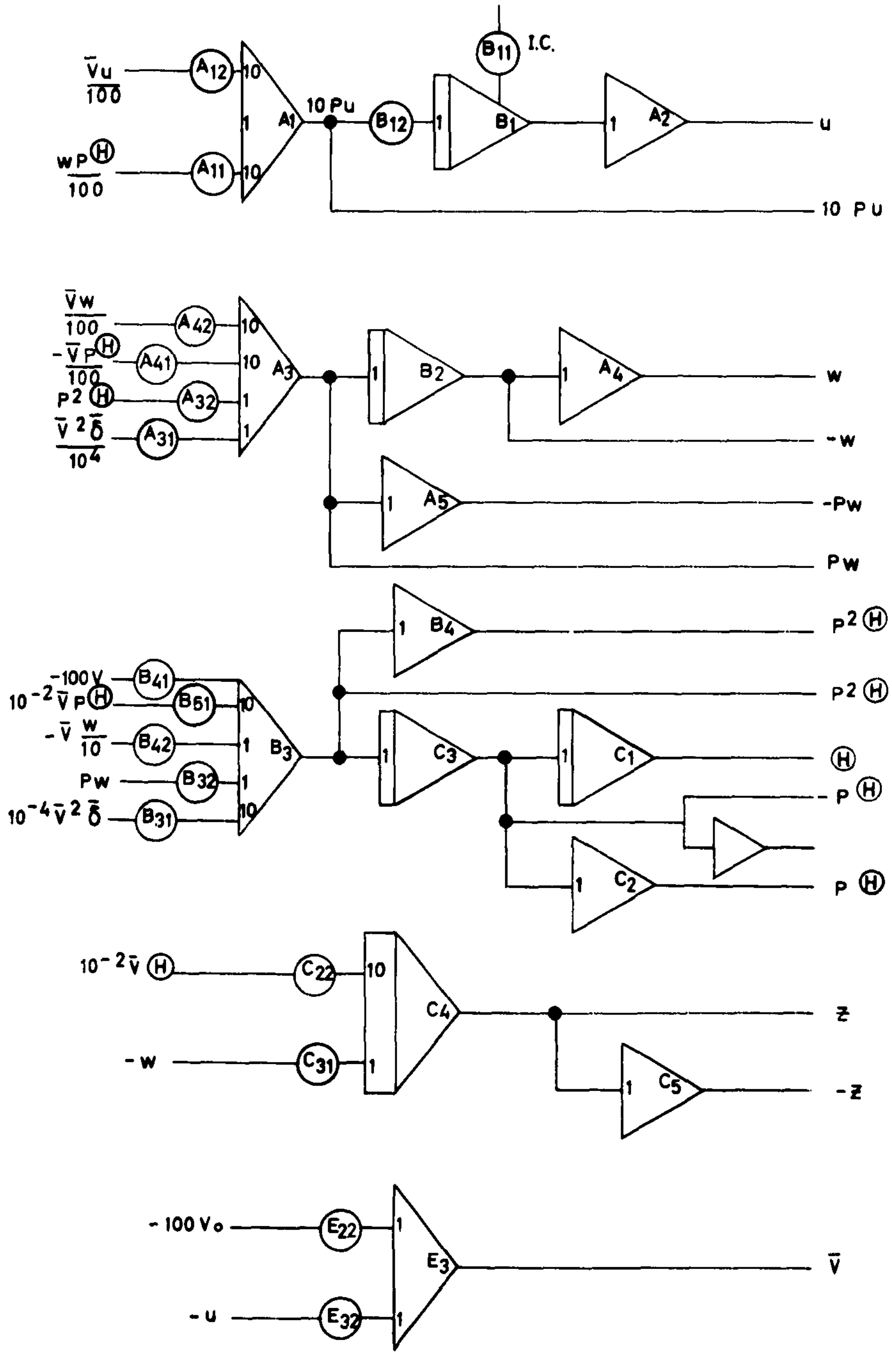
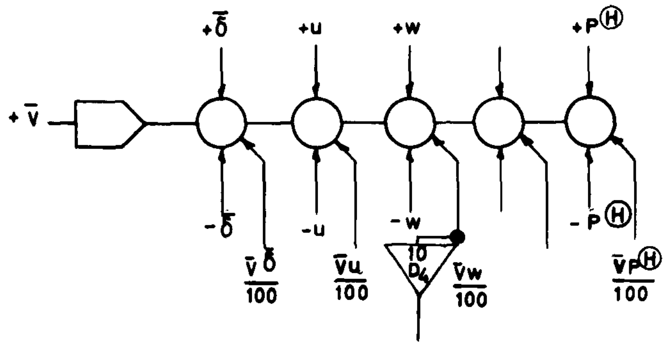


FIG. 1 MARK 8 TORPEDO - LONG NOSE

SERVO - MULTIPLIER



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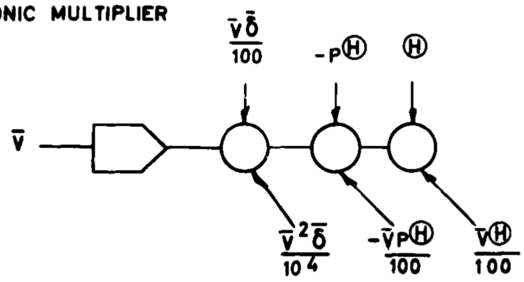


ELECTRONIC MULTIPLIER

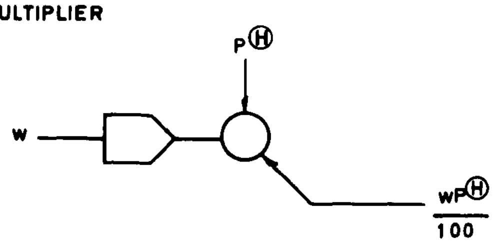


FIG.2 MARK 8 TORPEDO - LONG NOSE (contd)

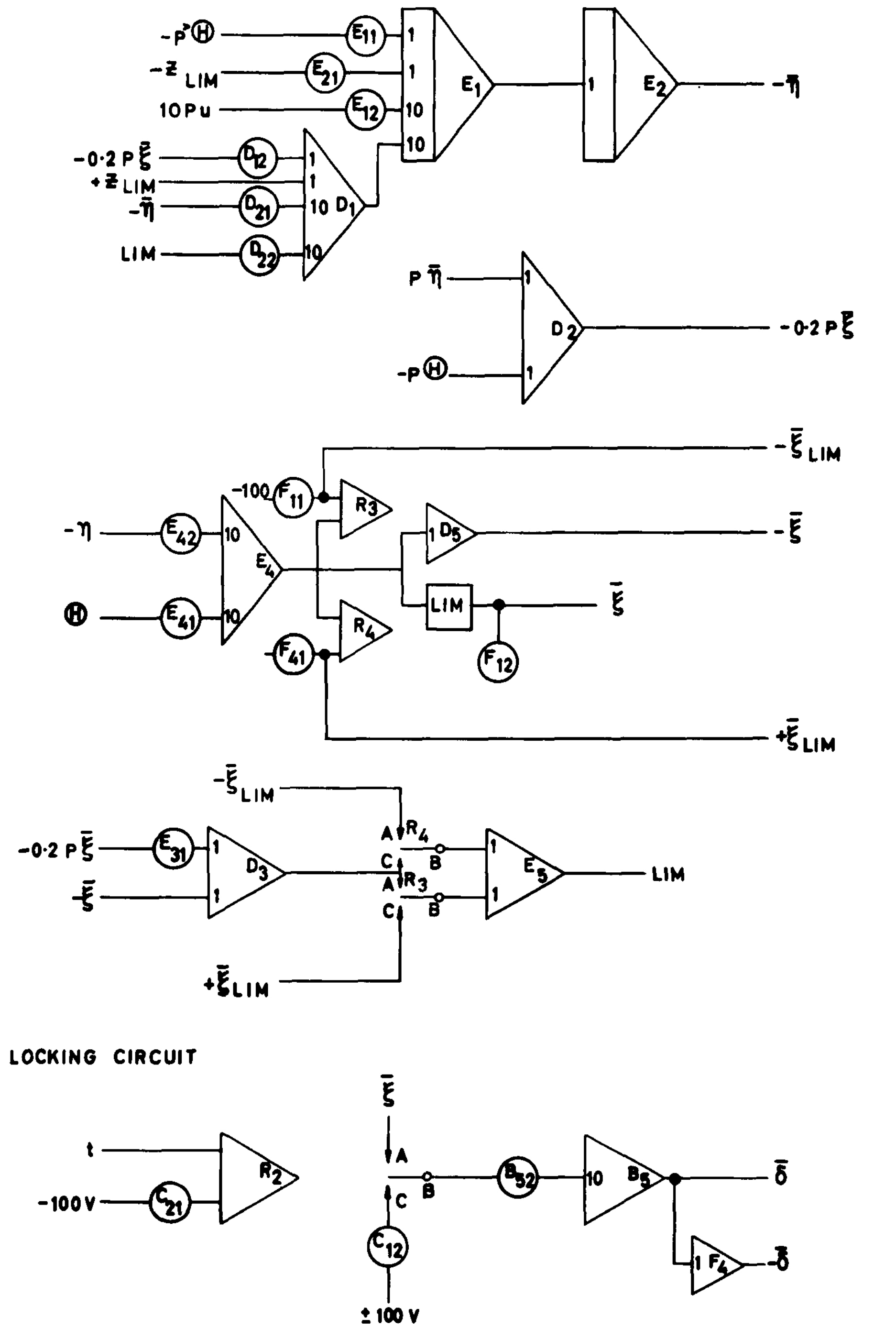
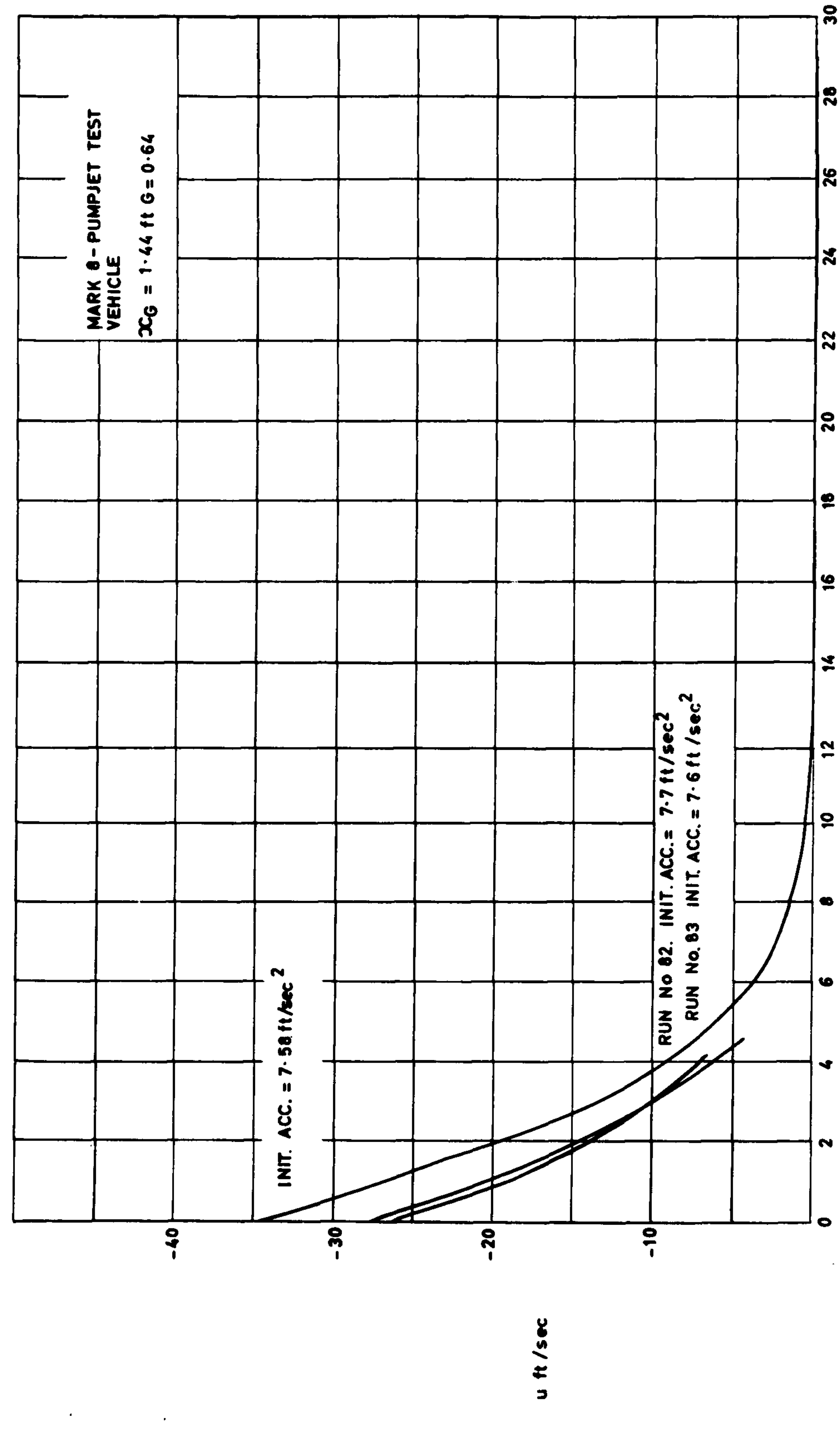


FIG. 3 MARK 8 TORPEDO - LONG NOSE. CONTROL SYSTEM


MARK 8 - PUMPJET TEST VEHICLE
x_G = 1·44 ft G = 0·64
INIT. ACC. = 7·58 ft/sec²
RUN No 82. INIT. ACC. = 7·7 ft/sec²
RUN No. 83 INIT. ACC. = 7·6 ft/sec²
-40
-30
-20
-10
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
u ft/sec

t secs
FIG. 4

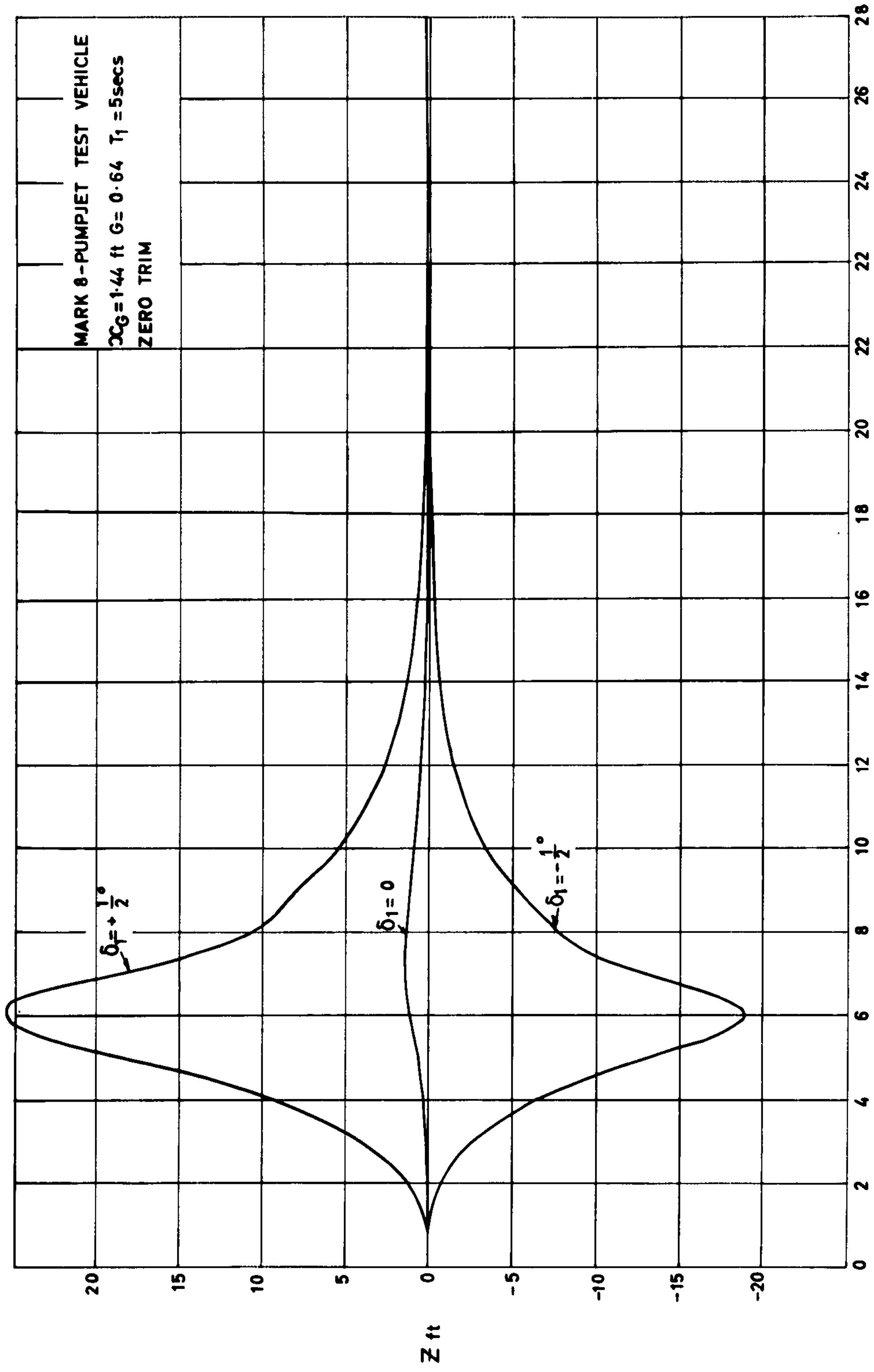

MARK 8-PUMPJET TEST VEHICLE
xG=1·44 ft G= 0·64 T1 =5secs
ZERO TRIM
δ1 = +1/2°
δ1 = 0
δ1 = -1/2°
t secs
Z ft

FIG 5

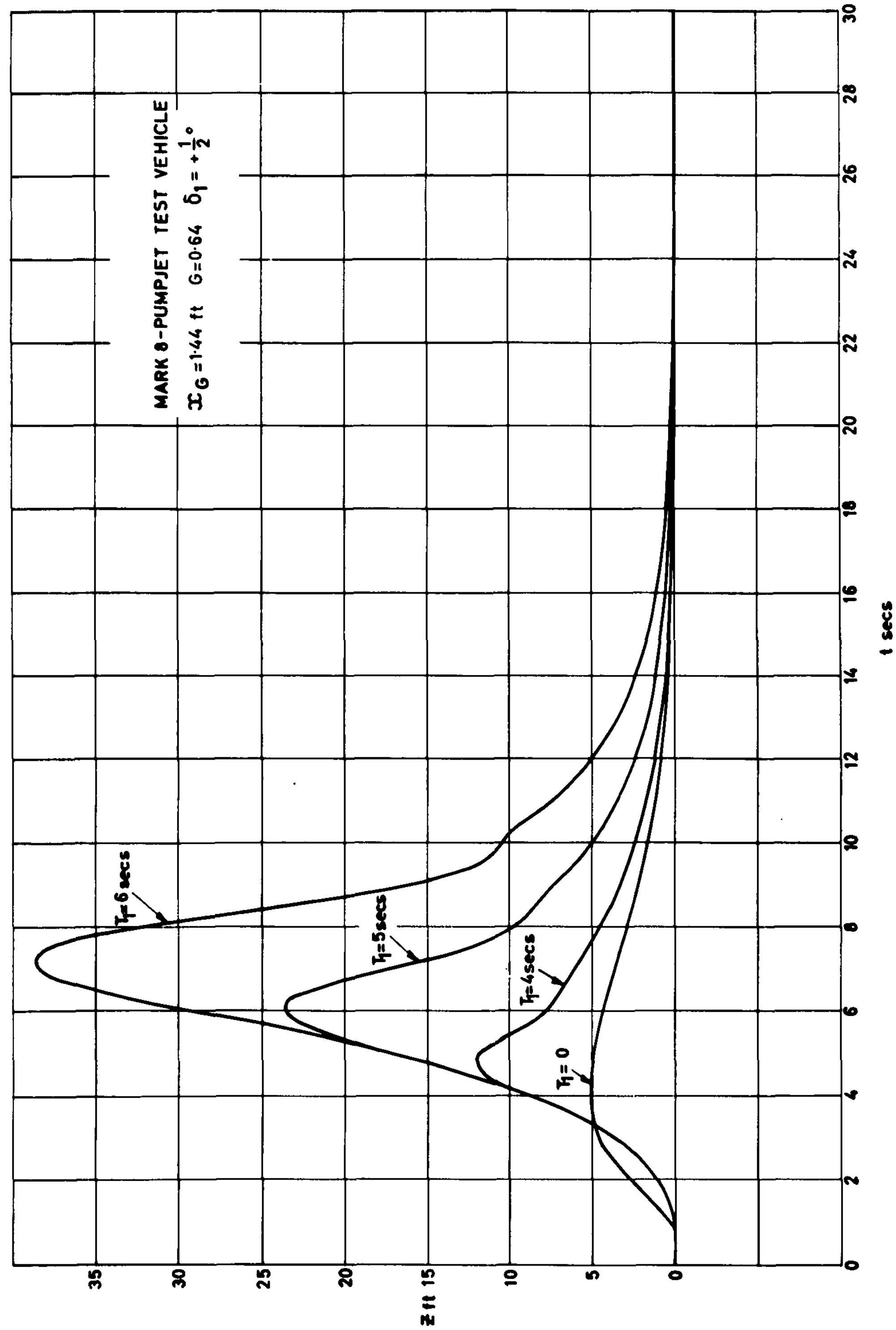
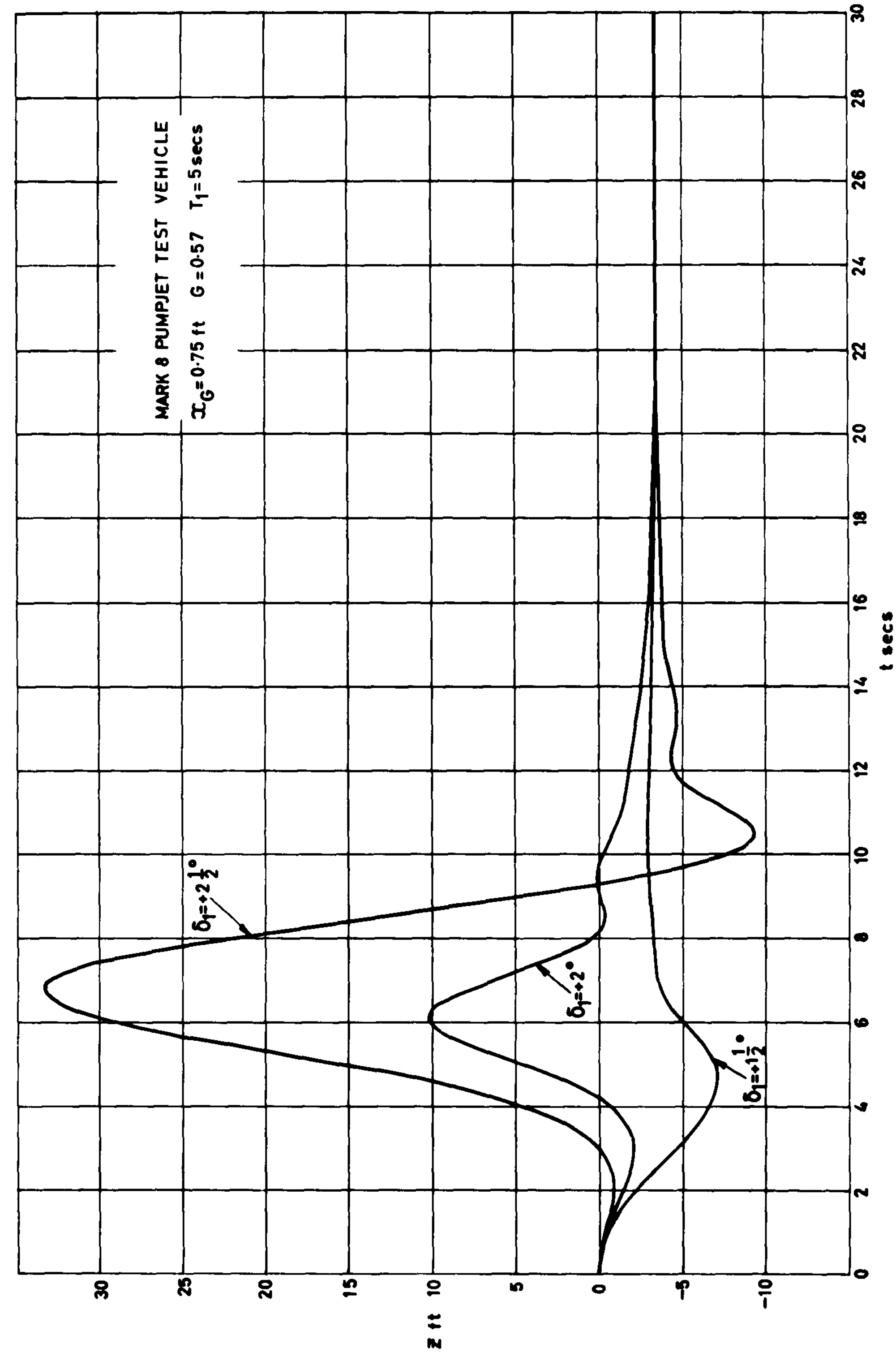
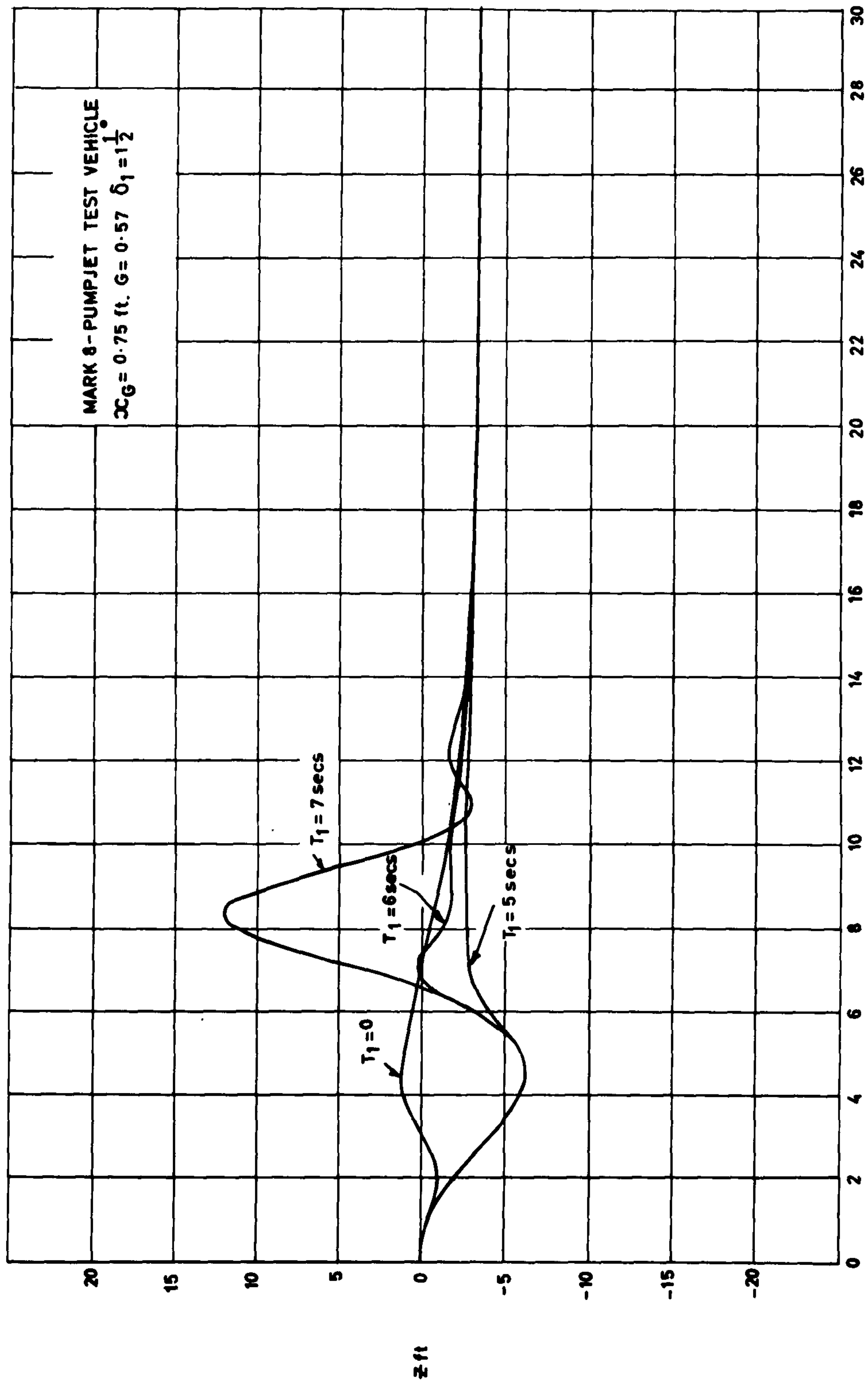

MARK 8-PUMPJET TEST VEHICLE
x_G = 1·44 ft G=0·64 $\delta_1 = +\frac{1}{2}°$
T_1=6 secs
T_1=5secs
T_1=4secs
T_1= 0
z ft
t secs

FIG. 6



MARK 8 PUMPJET TEST VEHICLE
x_G=0·75 ft G=0·57 T_1=5 secs
$\delta_1=+2\frac{1}{2}°$
$\delta_1=+2°$
$\delta_1=+1\frac{1}{2}°$
z ft
30
25
20
15
10
5
0
-5
-10
t secs
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30

FIG. 7


MARK 8-PUMPJET TEST VEHICLE
x_G = 0·75 ft. G = 0·57 $\delta_1 = 1\frac{1}{2}^\circ$
T_1 = 7 secs
T_1 = 6 secs
T_1 = 5 secs
T_1 = 0
z ft
20 15 10 5 0 -5 -10 -15 -20
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30

t secs

FIG. 8

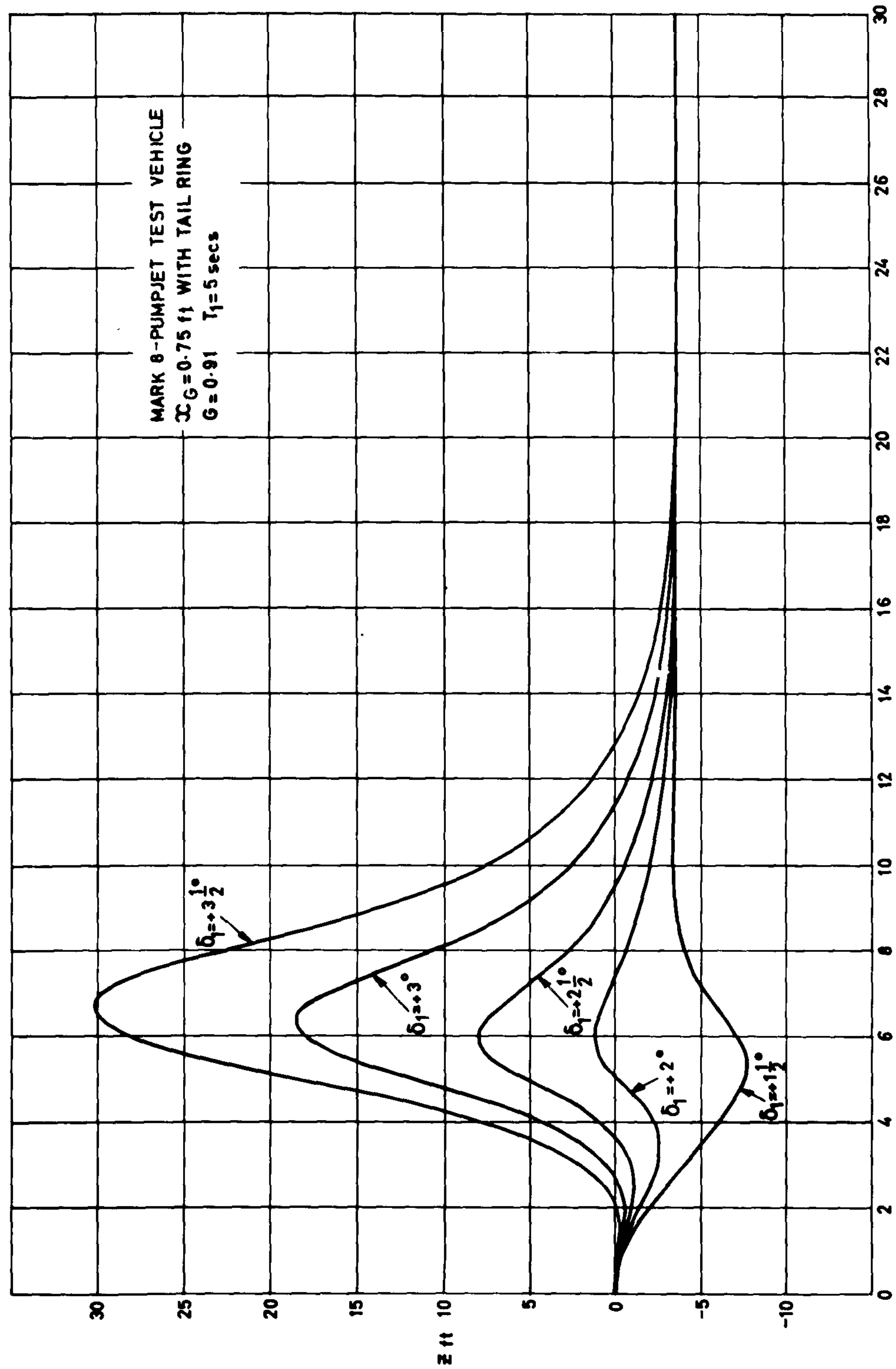
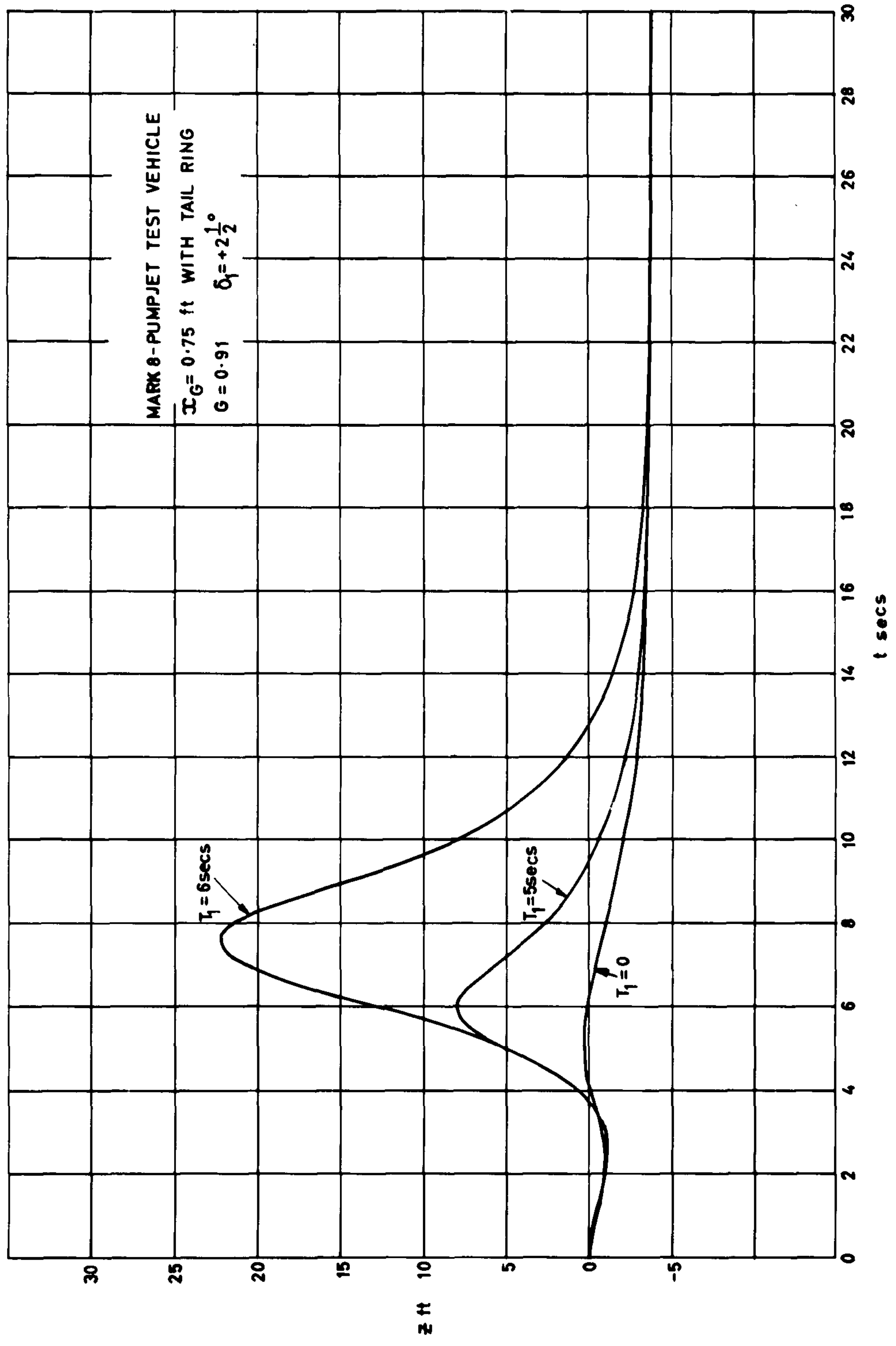

MARK 8-PUMPJET TEST VEHICLE
x_G=0·75 ft WITH TAIL RING
G=0·91 T_1=5 secs
δ_1=+3$\frac{1}{2}$°
δ_1=+3°
δ_1=+2$\frac{1}{2}$°
δ_1=+2°
δ_1=+1$\frac{1}{2}$°
z ft
t secs

FIG. 9



MARK 8-PUMPJET TEST VEHICLE
x_G= 0·75 ft WITH TAIL RING
G = 0·91 δ_1=+2½°
T_1=6secs
T_1=5secs
T_1=0
t secs
z ft
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
30 25 20 15 10 5 0 -5

FIG. 10

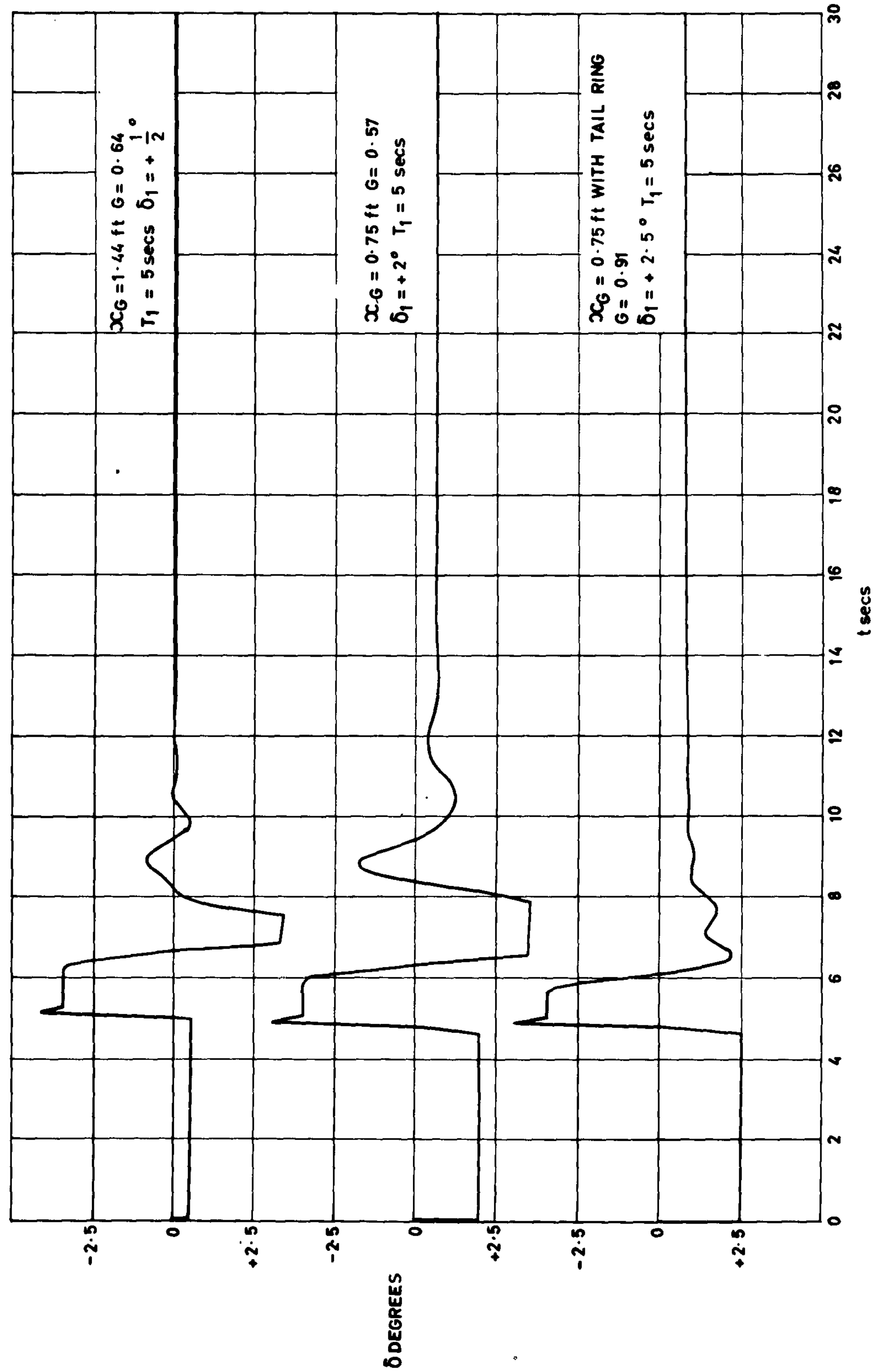

x_G = 1·44 ft G = 0·64
T_1 = 5 secs δ_1 = + $\frac{1}{2}$°
x_G = 0·75 ft G = 0·57
δ_1 = + 2° T_1 = 5 secs
x_G = 0·75 ft WITH TAIL RING
G = 0·91
δ_1 = + 2·5° T_1 = 5 secs
-2·5
0
+2·5
δ DEGREES
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
t secs

FIG. 11

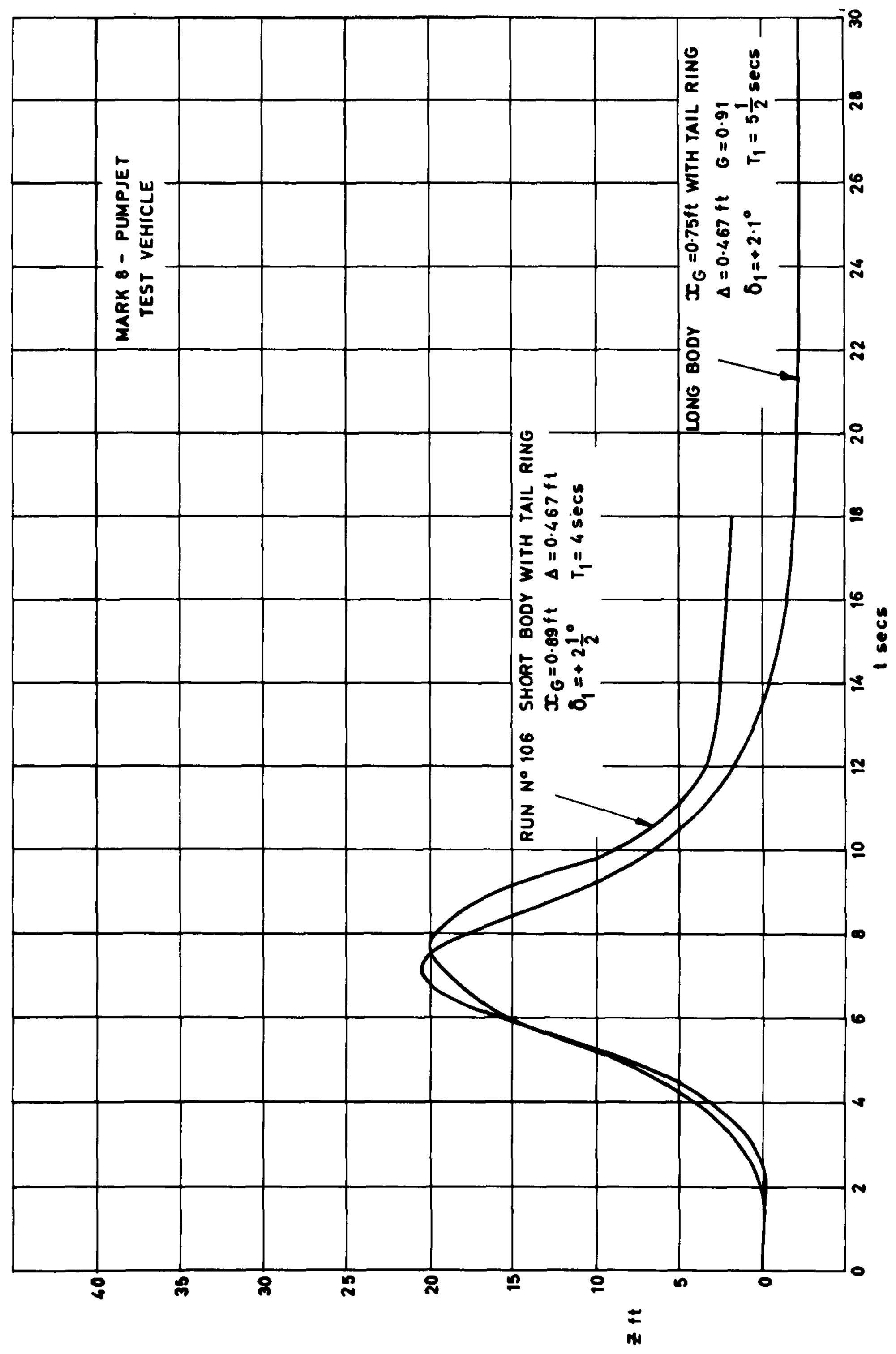


FIG. 12

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